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by David W. Reichard, Richard J. Parker, and Erwin V. Zaretsky

Lewis Research Center
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SUMMARY

Subsurface residual stress measurements were made on SAE 52100 steel inner races from 207-size deep-groove ball bearings in which ΔH (ball hardness minus race hardness) ranged from -1.1 to 3.5 points Rockwell C. Nominal Rockwell C hardness of the inner and outer races was 63. These bearings had been run at an inner-race speed of 2750 rpm and a radial load of 1320 pounds (5874 N) producing maximum Hertz stresses of 352 000 and 336 000 psi (2425×10^6 and 2315×10^6 N/m^2) at the inner and outer races, respectively. The lubricant was a super-refined naphthenic mineral oil. The residual stress measurements were made at various depths below the inner-race running track surface for a total of 19 of these bearings that had been run for nominally 200, 600, and 1600 hours. The measurements indicated that the maximum compressive residual stresses occur in approximately the same ΔH range for which the maximum fatigue lives were observed. Additionally, no relation between running time and residual stress could be determined from these measurements. Although a subsurface hardness decrease was evident in all cases, no relation between these changes and ΔH or running time could be determined.

INTRODUCTION

Research in the past several years has been directed toward increasing the life of rolling-element bearings (ref. 1). These efforts have led to increased operational reliability in industrial and aerospace components. While much progress has been made in optimizing the design parameters and improving materials, rolling-element bearings still fail from fatigue. It is therefore desirable to continue the investigation of fatigue phenomena and to develop ways of further increasing bearing life and reliability.

Among the factors which can affect the fatigue life of a rolling-element bearing is residual stress (ref. 2). Residual stresses can be induced in a material by such methods as heat treating, rolling, shot peening, sandblasting, and severe grinding. Residual stress can either increase or decrease the maximum shearing stress (ref. 3) according to the following equation:

$$(\tau_{max})_r = \tau_{max} - \frac{1}{2}(\pm S_r)$$

where $(\tau_{max})_r$ is the maximum shearing stress modified by the residual stress, S_r, and τ_{max} is the maximum shearing stress due to the applied load. The positive or negative sign indicates a tensile or compressive residual stress, respectively. A compressive residual stress would reduce the magnitude of the maximum shearing stress (because the value of τ_{max} is negative) and increase fatigue life according to the inverse relation between life and stress where

$$\text{Life} \propto \left[\frac{1}{(\tau_{max})_r}\right]^9$$

Researchers reported in references 4 and 5 that these compressive residual stresses induced prior to operation do indeed increase fatigue life. Additional research indicated that compressive residual stresses are developed during bearing operation (ref. 6). The magnitude of rolling-contact induced residual stresses was related to ΔH (ball hardness minus race hardness). In reference 3, an interrelation was indicated among ΔH, induced compressive residual stress, and fatigue life. The apparent maximum residual stress occurred above where ΔH was equal to 0.

The objectives of this research were to determine for full-scale bearings (1) the relation between residual stress (as a function of depth below the rolling-element surface) and component hardness differences ΔH, (2) the correlation among ΔH, residual stress, and fatigue life, and (3) whether a relation exists between induced compressive residual stress and running time.

In order to accomplish these objectives, residual stress measurements were made at varying depths below the running track surface on SAE 52100 steel inner races from 207-size deep-groove ball bearings. These bearings (refs. 7 and 8) established a relation between ΔH and rolling-element fatigue. Bearing operating conditions included an inner-race speed of 2750 rpm, a radial load of 1320 pounds (5874 N) which produced maximum Hertz stresses of 352 000 and 336 000 psi (2425×10^6 and 2315×10^6 N/m^2) at the inner and outer races, respectively, and a super-refined naphthenic mineral oil as the lubricant.

PROCEDURE

Three bearing groups were chosen: those which had been run for time intervals of 200 to 300, 600 to 700, and 1600 to 1800 hours. Each time group had bearings with ΔH values ranging from -1.1 to 3.5 points Rockwell C. Subsurface residual stress and hardness measurements were made using standard X-ray diffraction techniques (refs. 9 and 10). Each inner race was examined in the region directly beneath the running track. An electropolishing technique was used to remove material at varying depths (to 0.007 inch or 0.018 cm) below the surface.

RESULTS AND DISCUSSION

Effect of Component Hardness Differences on Residual Stress

Residual stress measurements were made using standard X-ray diffraction techniques at varying depths below the running track surface. Three groups of SAE 52100 steel inner races from 207-size deep-groove ball bearings were measured. Operating conditions for these bearings included an inner-race speed of 2750 rpm and a radial load of 1320 pounds (5874 N) which produced maximum Hertz stresses of 352 000 and 336 000 psi (2425×10^6 and 2315×10^6 N/m^2) at the inner and outer races, respectively.

The residual stress pattern typical for an unrun bearing inner race is shown in figure 1. As can be seen, there exists a relatively high compressive residual stress very close to the surface which is a result of the fabricating process. This residual stress very rapidly approaches zero just below the surface.

The residual stress pattern usually found beneath the surface of rolling-element bearing inner races that have been run is also shown in figure 1. The characteristic feature of this stress pattern is the high compressive stress at the surface. This stress decreases rapidly with depth, gradually levels out at some depth, and then decreases to zero.

The residual stress measurements with varying values of ΔH for the 207-size deep-groove ball bearing inner races as a function of depth below the surface are summarized in table I for time intervals of 200 to 300 hours, 600 to 700 hours, and 1600 to 1800 hours. These residual stress data are also plotted in figures 2 to 4 as a function of depth below the surface for each of the time intervals.

For the time interval of 200 to 300 hours summarized in figure 2(e) no definitive relation between ΔH and residual stress is noted. The maximum value of compressive residual stress was approximately 51×10^3 psi (351×10^6 N/m^2) at 0.003 inch (0.008 cm) below the surface for the ΔH of -1.3 points Rockwell C. The maximum orthogonal shearing stress which is illustrated in figure 5 was calculated to be approximately 0.003 inch (0.008 cm) below the running track surface in these bearing races. The maximum shearing stress which is on a 45° plane to the surface was calculated to be 0.006 inch (0.015 cm) below the running track surface.

For the time interval of 600 to 700 hours summarized in figure 3(i), a distinct relation between ΔH and residual stress is apparent. The maximum residual stress value occurs at a ΔH of 1.3 points Rockwell C; the maximum value being 103×10^{3} psi (896×10^{6} N/m^{2}) at a depth 0.002 inch (0.005 cm) below the surface. The low residual stress values occur at the extreme ΔH values. Higher residual stress values occur at the intermediate ΔH values.

The time interval of 1600 to 1800 hours is summarized in figure 4(h). As for the time interval of 600 to 700 hours, a distinct relation is noted between ΔH and residual stress. Here again residual stress apparently increases to an intermediate value of ΔH and then begins to decrease. The maximum residual stress values occur at a ΔH of 2.2 points Rockwell C. The maximum residual stress value at this ΔH is 78×10^{3} psi (537×10^{6} N/m^{2}) at a depth of 0.002 inch (0.005 cm) below the surface.

In order to better illustrate the effect of ΔH on residual stress, these stresses at a depth of 0.002, 0.004 and 0.006 inch (0.005, 0.010 and 0.015 cm) below the surfaces are plotted as a function of ΔH in figures 6 to 8. Here again, it can be seen that residual stress increases to a maximum at an intermediate value of ΔH. For the 200- to 300-hour time interval no clear relation with ΔH is apparent.

Effect of Running Time on Residual Stress

Investigators have reported that the magnitude of the residual stress in rolling-element bearings increases with increasing running time (ref. 6). To verify this phenomenon, the data of table I are presented in figure 9 with residual stress plotted as a function of depth for various running times within a particular ΔH range. In general, no relation of induced residual stress and running time is apparent. It is speculated that, if residual stress is a function of time, the maximum residual stress values were reached before 200 hours of operation in the tests reported.

Effect of Residual Stress on Fatigue Life

In references 11 and 12, the maximum orthogonal shearing stress was assumed to be the critical stress instrumental in the rolling-element fatigue process. This assumption is reasonably valid if one considers that the maximum reversal of shearing stress occurs on the orthogonal plane. However, metallurgical investigation (ref. 13) of failed rolling-element specimens suggests that the maximum shearing stress, which is on a 45^{o} plane, is the most critical stress. The peak amplitude of the maximum shearing stress is greater than that of the maximum orthogonal shearing stress. The variation of shearing stress on a 45^{o} plane and the orthogonal shearing stress are illustrated and compared in figure 10.

For the bearing race specimens previously discussed, the peak amplitude of the maximum orthogonal shearing stress τ'_{zy} occurred at a depth of approximately 0.003 inch (0.008 cm) below the running track surface; whereas the peak amplitude of the maximum shearing stress τ_{max} occurred at a depth of approximately 0.006 inch (0.015 cm). The maximum induced compressive residual stress occurs in these races for the various time intervals at a depth of 0.002 to 0.003 inch (0.005 to 0.008 cm) below the running track surface which corresponds to depth of the maximum orthogonal shearing stress. This correlation would suggest that the orthogonal shearing stress is that which is instrumental in inducing the residual stress.

The question remains whether the orthogonal stress is, in turn, modified by the residual stress buildup. If a two dimensional model is considered where it is assumed that the residual stress occurs only in the direction of rolling, a simple analysis indicates that this residual stress is added to any principal Hertzian stress distribution caused by two bodies in contact. A further analysis indicates a significant change in the maximum shearing stress but no change in the maximum orthogonal shearing stress.

Fatigue results (refs. 7 and 8) for the bearing specimens reported herein indicated that fatigue lives increased with increasing ΔH to a ΔH value between 1 and 2 points Rockwell C (fig. 11) and then decreased for a further increase in ΔH. The maximum induced residual compressive stresses occurred in the same range of ΔH as did the maximum fatigue lives. These results substantiate an interrelation among ΔH, induced compressive residual stresses, and fatigue life. However, because the residual stresses affect the values of shearing stress on a 45^{o} plane and not the orthogonal stress, it must be concluded that the prime stress responsible for affecting fatigue life is the maximum shearing stress.

Using the equations for $(\tau_{max})_r$ and life previously presented, the relative lives were calculated based on the residual stresses given in table I at the depth of the maximum shearing stress, 0.006 inch (0.015 cm) below the running track surface. These results are compared with the relative experimental lives from references 7 and 8 in table II. As can be seen, there is a qualitative correlation between the relative predicted lives and the relative lives determined experimentally. In both cases, the peak value occurs at a ΔH between 1 and 2 points Rockwell C. At a depth of 0.006 inch (0.015 cm) for a running time of 1600 to 1800 hours, the peak life prediction would have been at a ΔH between 2 and 3 points Rockwell C. For the 200- to 300-hour running time, no life trend could have been predicted based on residual stress effects at the depth of the maximum shearing stress.

Subsurface Hardness Changes

Figure 12 shows the hardness values as a function of depth below the running track surface for a run and unrun bearing inner race. As can be seen, a decrease in hardness occurs beneath the surface of the running track of the bearing race run for 3480 hours. Subsurface hardness measurements were obtained from the X-ray diffraction data to determine whether running time or ΔH affected subsurface hardness. Figures 13 to 15 are plots of subsurface hardness values as a function of depth for the three running time groups.

As was expected from the preliminary data discussed previously, a decrease in subsurface hardness, on the order of several points Rockwell C, occurred with all the bearing races. However, there was no correlation of running time or ΔH with these subsurface hardness changes.

There may be a hardness dip represented by the dashed lines in the hardness profiles (on the order of one point Rockwell C) in figures 11 to 13. This phenomena may be the same as reported in reference 14 for bearing races run at a maximum Hertz stress of 470 000 psi (3238×10^6 N/m^2). (This stress is 34 percent higher than the stress employed in the investigation reported herein.) The "hardness dip" reported in reference 14 was as much as 6 points Rockwell C. If this "hardness dip" does exist, it is speculated that the difference in the magnitude of the dips for the data reported herein and those of reference 11 may be accounted for by the different test conditions or may represent different stages in a subsurface tempering process. However, there is no apparent interrelation between the "hardness dip" and ΔH or fatigue life.

SUMMARY OF RESULTS

Subsurface residual stress and hardness measurements were made on three groups of SAE 52100 steel inner races from 207-size deep-groove ball bearings which had been run for approximately 200, 600, or 1600 hours. Operating conditions included an inner-race speed of 2750 rpm, a radial load of 1320 pounds (5874 N), which produced maximum Hertz stresses of 352 000 and 336 000 psi (2425×10^6 and 2315×10^6 N/m^2) at inner and outer races, respectively, and a super-refined naphthenic mineral oil as the lubricant. Each group of bearings had a range of ΔH (ball hardness minus race hardness) from -1.1 to 3.5 points Rockwell C. The following results were obtained:

1. A trend exists showing maximum values of induced subsurface compressive residual stresses at intermediate values of ΔH for running times greater than 300 hours. The peak value of residual stress apparently occurs in the same range of ΔH for which maximum fatigue life occurs.

2. Maximum values of induced compressive residual stresses occurred at a depth between 0.002 and 0.003 inch (0.005 and 0.010 cm) which corresponds to the depth of the maximum orthogonal shearing stress, 0.003 inch (0.010 cm) below the running track surface.

3. No clear effect of running time on induced compressive residual stress was observed.

4. There was a small decrease in inner-race hardness below the running track surface. This decrease was apparently not a function of either ΔH or running time.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 9, 1967,
126-15-02-16-22.

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TABLE I. - MEASURED RESIDUAL STRESS WITH VARIOUS VALUES OF COMPONENT HARDNESS DIFFERENCE[a], ΔH, FOR 207-SIZE DEEP-GROOVE BALL BEARING INNER RACES

[Radial load, 1320 lb (5874 N); inner-race speed, 2750 rpm.]

(a) U.S. customary units

Component hardness difference, ΔH, Rockwell C	Running time, hr	Depth below running track surface, in.								
		0	0.0005	0.001	0.002	0.003	0.004	0.005	0.006	0.007
		Residual stress, ksi[b]								
Running times between 200 and 300 hr										
-1.3	210	-111	-46	-45	-46	-51	-47	-39	-32	-25
1.1	210	-92	-37	-27	-30	-28	-24	-18	-13	-11
3.1	281	-128	-83	-53	-35	-30	-28	-23	-23	-22
3.6	230	-95	-48	-33	-26	-21	-18	-15	-16	-13
Running times between 600 and 700 hr										
-1.2	648	-134	+4	+4	+1	-2	-2	-2	-5	-7
-1.2	697	-142	-69	-40	-14	-9	-6	-8	-8	-7
-1.0	653	-66	-46	-9	-5	-3	-7	-6	-6	-8
-.5	691	-105	-43	-41	-54	-68	-73	-76	-67	-50
1.3	665	-98	-81	-94	-103	-97	-88	-79	-69	-58
2.5	614	-47	-63	-71	-68	-65	-56	-45	-38	-27
2.7	700	-92	-99	-66	-53	-53	-49	-43	-38	-28
3.2	614	-175	-62	-39	-13	-7	-6	-5	-6	-8
Running times between 1600 and 1800 hr										
-1.1	1674	-124	+12	+16	+3	+1	-2	-7	-7	-3
1.2	1722	-132	-104	-57	-60	-62	-63	-61	-52	-41
1.6	1767	-161	-92	-46	-19	-12	-12	-11	-10	-8
2.2	1690	-94	-68	-70	-78	-73	-71	-68	-60	-47
2.7	1733	-98	-52	-22	-15	-8	-31	-32	-29	-20
3.5	1684	-94	-90	-44	-10	-11	-11	-11	-7	-4
3.5	1764	-88	-100	-50	-18	-19	-15	-18	-15	-10

[a]Ball hardness minus race hardness, Rockwell C scale.
[b]Positive values denote tensile stress, negative values denote compressive stress.

TABLE I. - Concluded. MEASURED RESIDUAL STRESS WITH VARIOUS VALUES OF COMPONENT HARDNESS DIFFERENCE[a], ΔH, FOR 207-SIZE DEEP-GROOVE BALL BEARING INNER RACES

[Radial load, 1320 lb (5874 N); inner-race speed, 2750 rpm.]

(b) SI units

Component hardness difference, ΔH, Rockwell C	Running time, hr	Depth below running track surface, cm								
		0	0.0013	0.0025	0.0051	0.0076	0.0102	0.0127	0.0152	0.0178
		Residual stress, MN/m^2 [b]								
Running times between 200 and 300 hr										
-1.3	210	-765	-317	-310	-317	-351	-324	-269	-220	-172
1.1	210	-634	-255	-186	-207	-193	-165	-124	-90	-76
3.1	281	-882	-572	-365	-241	-207	-193	-158	-158	-152
3.6	230	-654	-331	-227	-179	-145	-124	-103	-110	-90
Running times between 600 and 700 hr										
-1.2	648	-923	+28	+28	+7	-14	-14	-14	-34	-48
-1.2	697	-978	-475	-276	-96	-62	-41	-55	-55	-48
-1.0	653	-455	-317	-62	-34	-21	-48	-41	-41	-55
-.5	691	-723	-296	-282	-372	-469	-503	-524	-462	-344
1.3	665	-675	-558	-648	-710	-668	-606	-544	-475	-400
2.5	614	-324	-434	-489	-469	-448	-386	-310	-262	-186
2.7	700	-634	-682	-455	-365	-365	-338	-296	-262	-193
3.2	614	-1206	-427	-269	-90	-48	-41	-34	-41	-55
Running times between 1600 and 1800 hr										
-1.1	1674	-854	+83	+110	+21	+7	-14	-48	-48	-21
1.2	1722	-909	-717	-393	-413	-427	-434	-420	-358	-282
1.6	1767	-1109	-634	-317	-131	-83	-83	-76	-69	-55
2.2	1690	-648	-469	-482	-537	-503	-489	-469	-413	-324
2.7	1733	-675	-358	-152	-103	-551	-214	-220	-200	-138
3.5	1684	-648	-627	-303	-69	-76	-76	-76	-48	-28
3.5	1764	-608	-689	-345	-124	-131	-103	-124	-108	-69

[a]Ball hardness minus race hardness, Rockwell C scale.
[b]Positive values denote tensile stress, negative values denote compressive stress.

TABLE II. - RELATIVE PREDICTED FATIGUE LIVES BASED ON RESIDUAL STRESS MEASUREMENTS OF 207-SIZE DEEP-GROOVE BALL-BEARING INNER RACES FOR VARIOUS VALUES OF COMPONENT HARDNESS DIFFERENCE ΔH

Component hardness difference[a] range, ΔH, Rockwell C	Average compressive residual stress value		Relative predicted 10-percent life from residual stress[b]	Relative experimental 10-percent life[b, c]
	ksi	MN/m^2		
-2.0 to -1.0	6	42	0.06	0.07
-1.0 to 0	36	248	.19	.23
0 to 1.0	--	---	----	----
1.0 to 2.0	69	475	1.00	1.00
2.0 to 3.0	38	262	.23	.83
3.0 to 4.0	6	42	.06	.60

[a]Ball hardness minus race hardness, Rockwell C scale.
[b]Relative to value at ΔH range 1.0 to 2.0.
[c]Refs. 7 and 8.

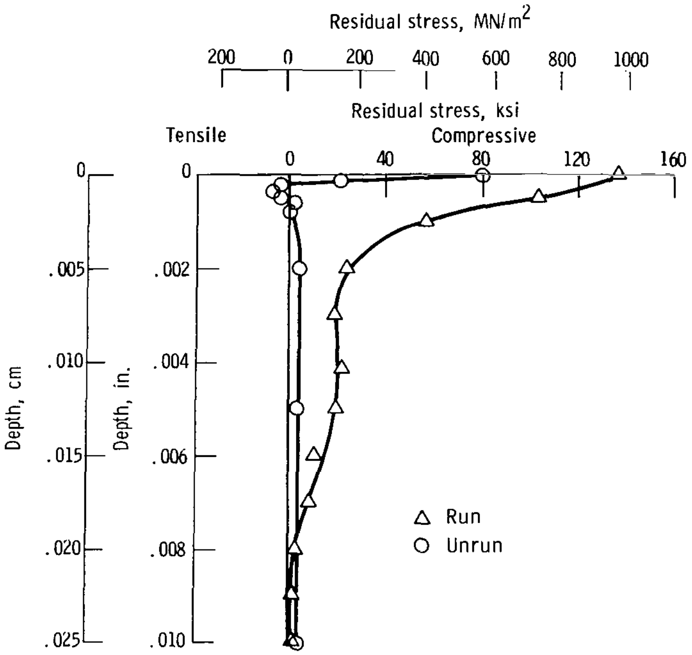


Figure 1. - Residual stress as function of depth below surface of 207-size deep-groove bearing inner races in both run (duration, 3480 hr) and unrun condition. Component hardness difference, $\Delta H = 2.0$ (ref. 7).

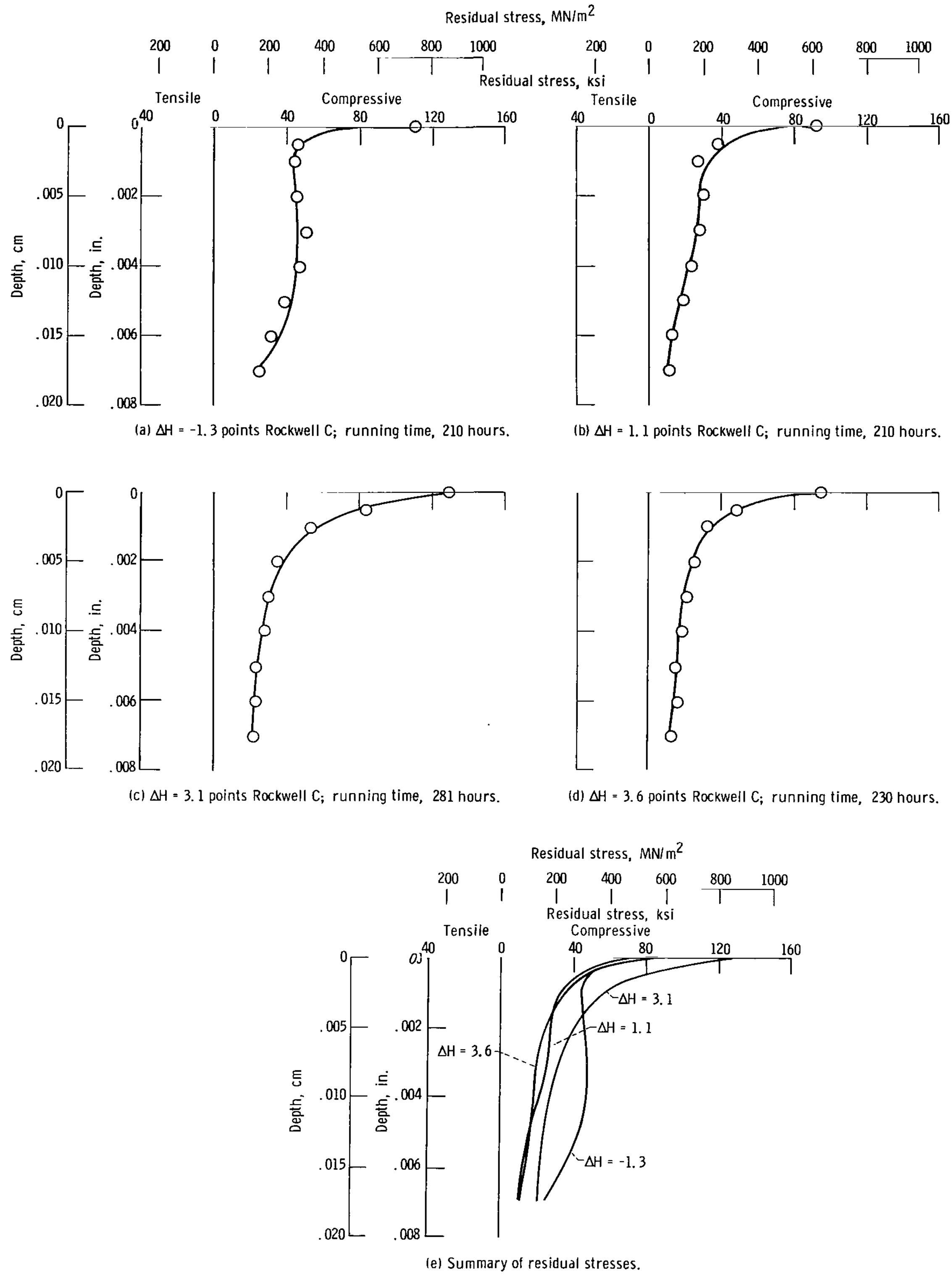


Figure 2. - Residual stress as function of depth for 207-size deep-groove ball bearings with various values of component hardness difference ΔH (ball hardness minus race hardness). Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added; running times, between 200 and 300 hours.

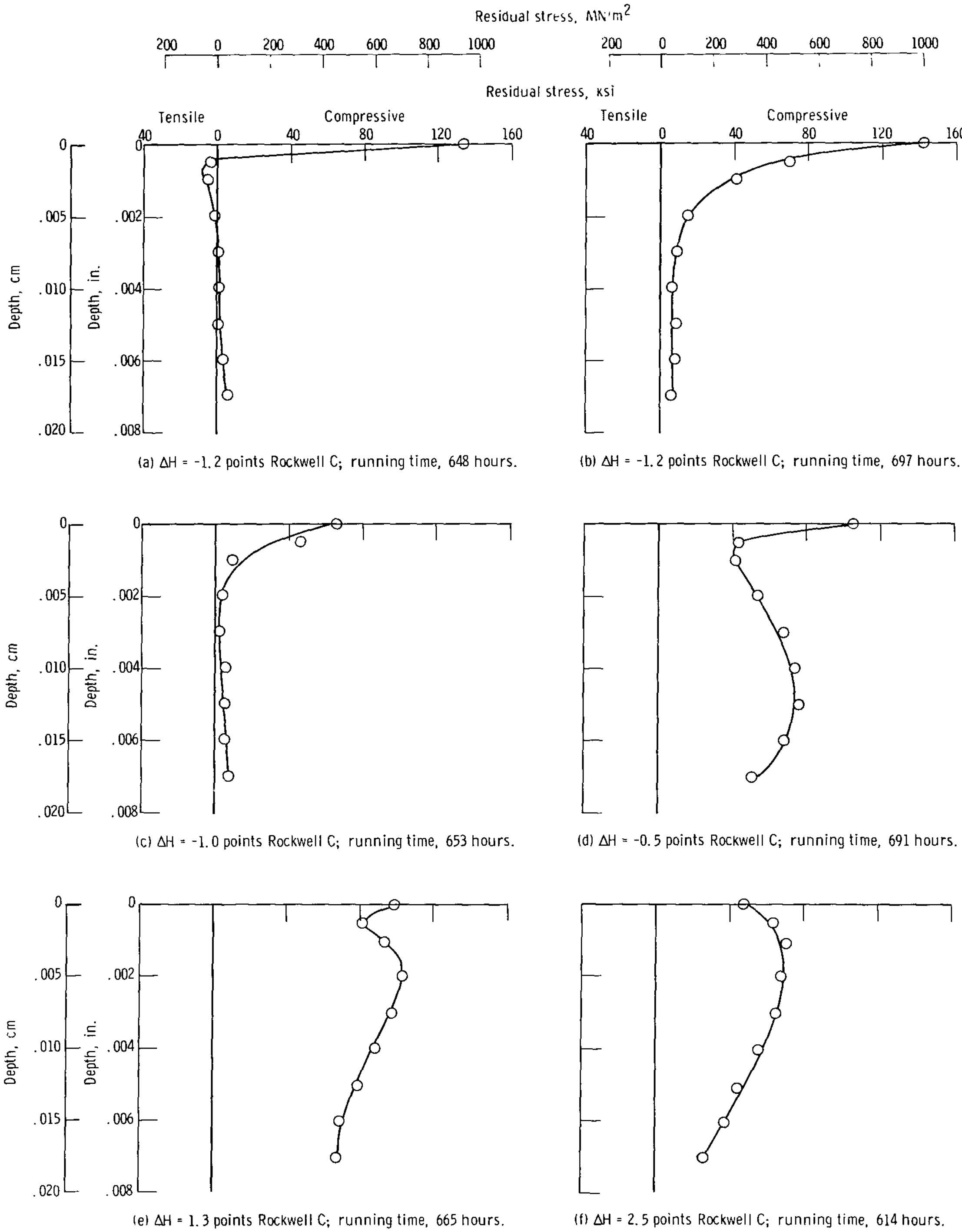
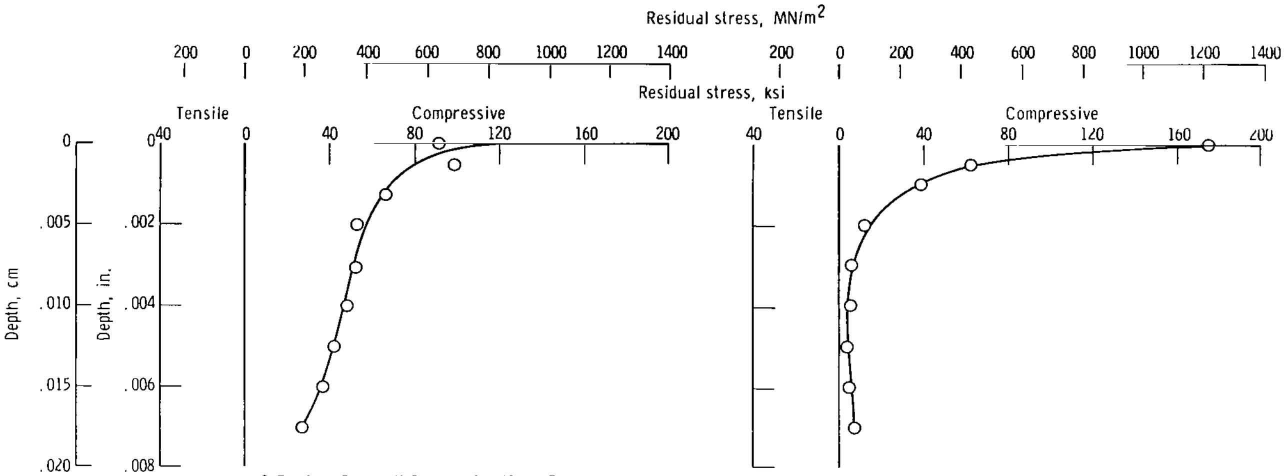
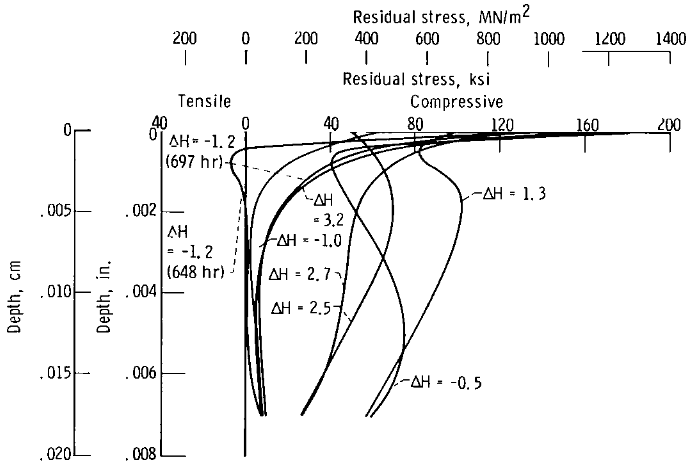


Figure 3. - Residual stress as function of depth for 207-size deep-groove ball bearings with various values of component hardness difference ΔH (ball hardness minus race hardness). Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added; running times, between 600 and 700 hours.



(g) ΔH, 2.7 points Rockwell C; running time, 700 hours.

(h) ΔH, 3.2 points Rockwell C; running time, 614 hours



(i) Summary of residual stresses.

Figure 3. - Concluded.

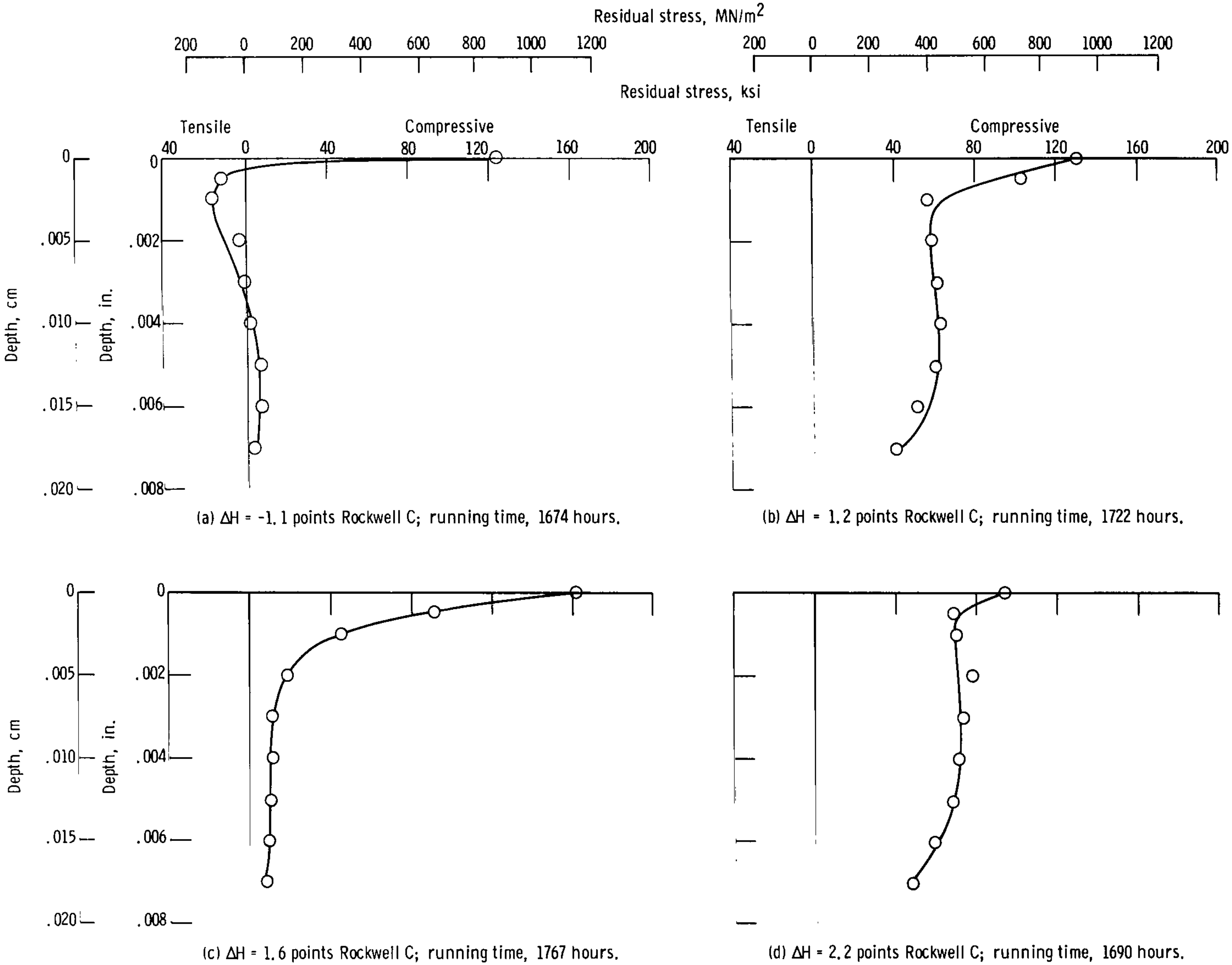
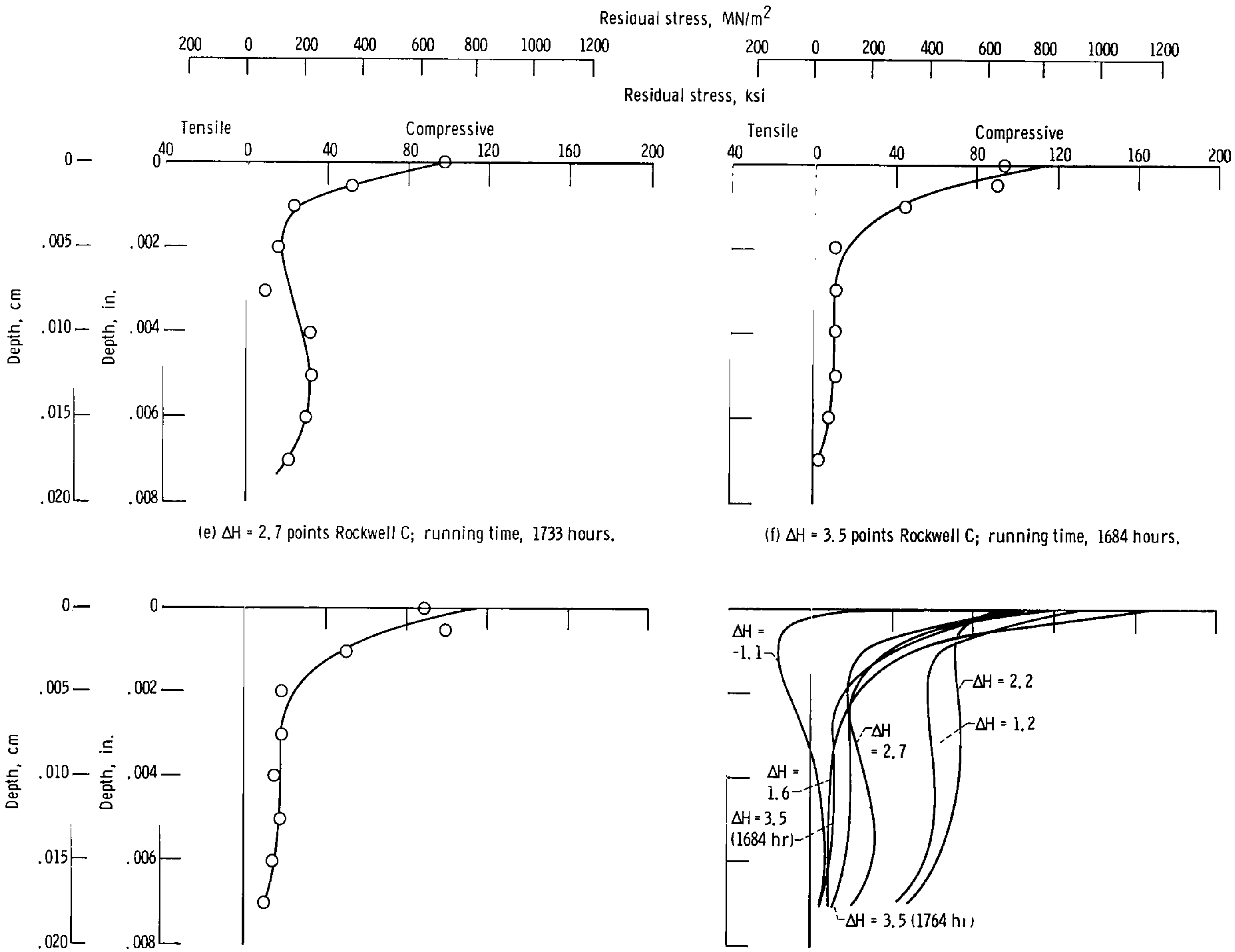


Figure 4. - Residual stress as function of depth for 207-size deep-groove ball bearings with various values of component hardness difference ΔH (ball hardness minus race hardness). Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added; running times, between 1600 and 1800 hours.



(e) ΔH = 2.7 points Rockwell C; running time, 1733 hours.

(f) ΔH = 3.5 points Rockwell C; running time, 1684 hours.

(g) ΔH = 3.5 points Rockwell C; running time, 1764 hours.

(h) Summary of residual stresses.

Figure 4. - Concluded.

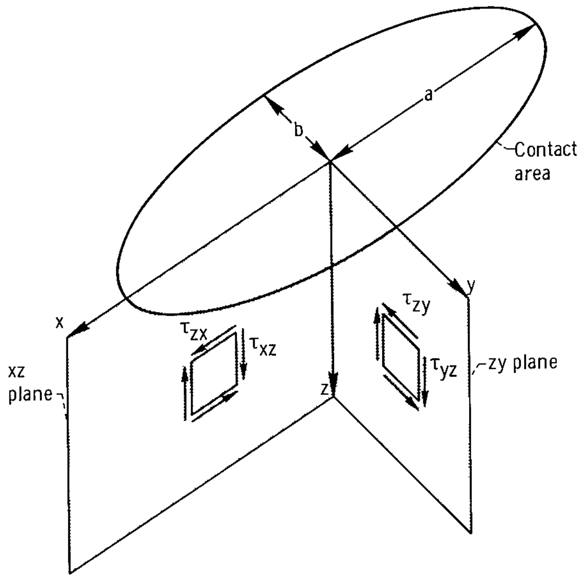


Figure 5. - Orthogonal shearing stresses.

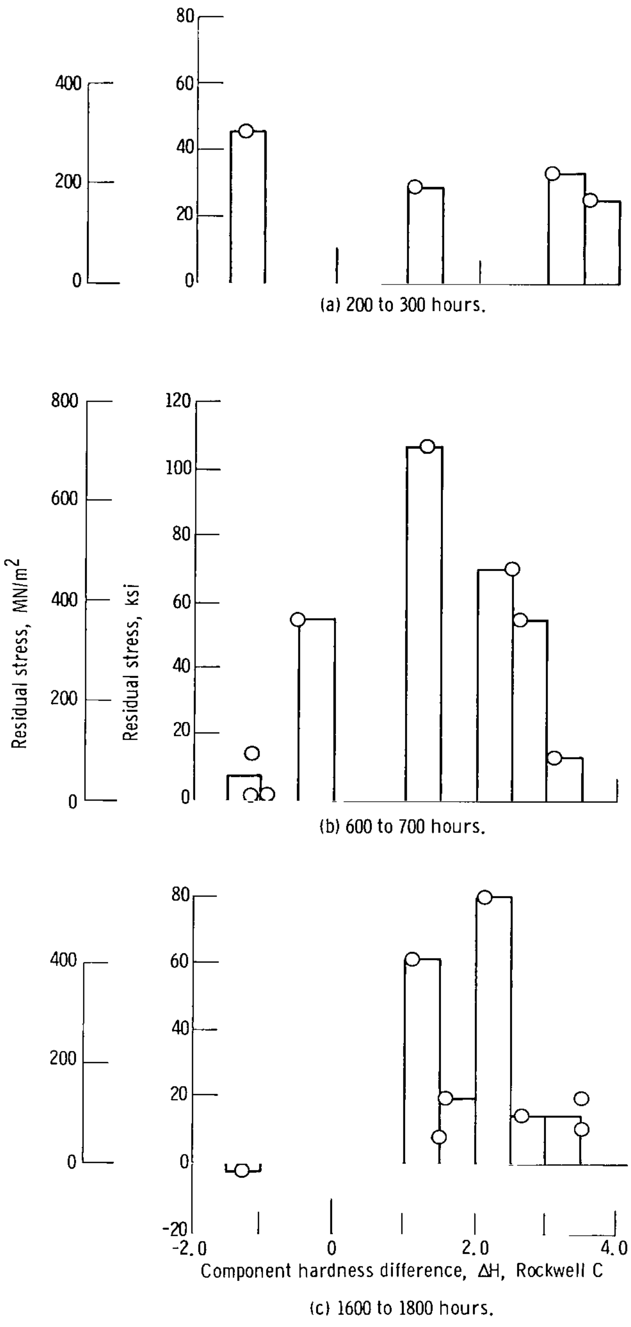


Figure 6. - Compressive residual stress as function of component hardness difference ΔH (ball hardness minus race hardness) for 207-size deep-groove bearing inner races. Depth below inner-race running track surface, 0.002 inch (0.005 cm); ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added.

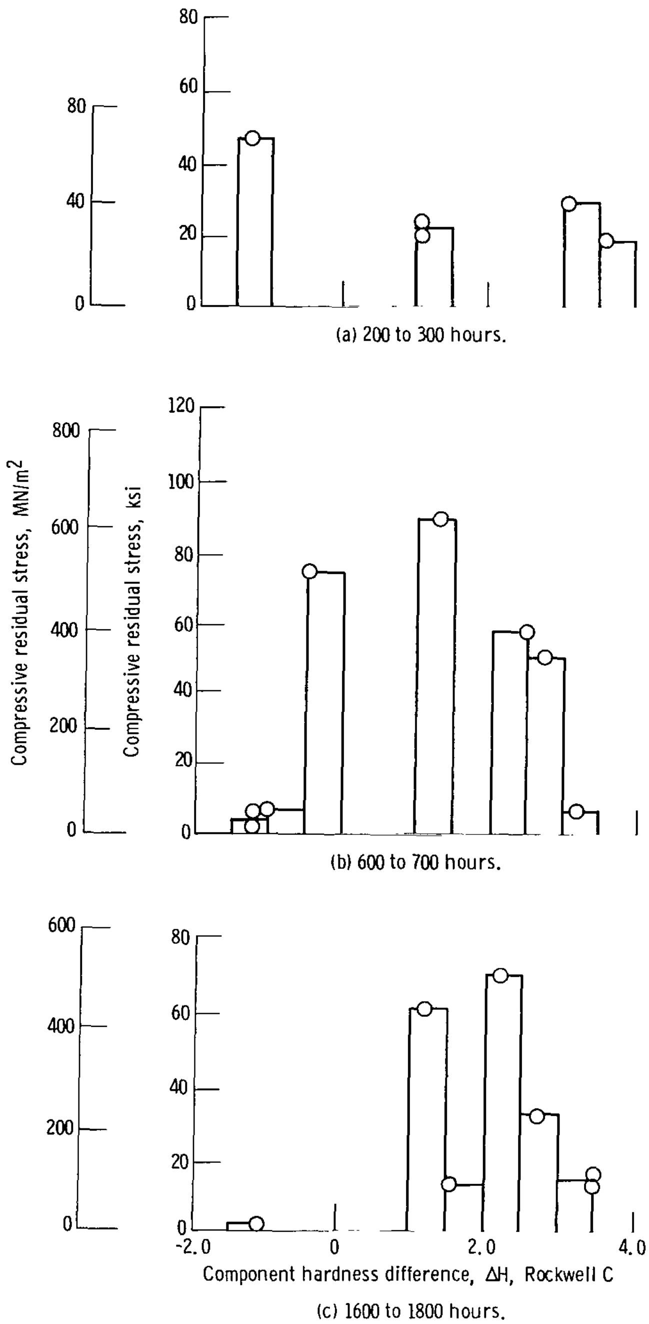


Figure 7. - Compressive residual stress as function of component hardness difference ΔH (ball hardness minus race hardness) for 207-size deep-groove bearing inner races. Depth below inner-race running track surface, 0.004 inch (0.010 cm); ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added.

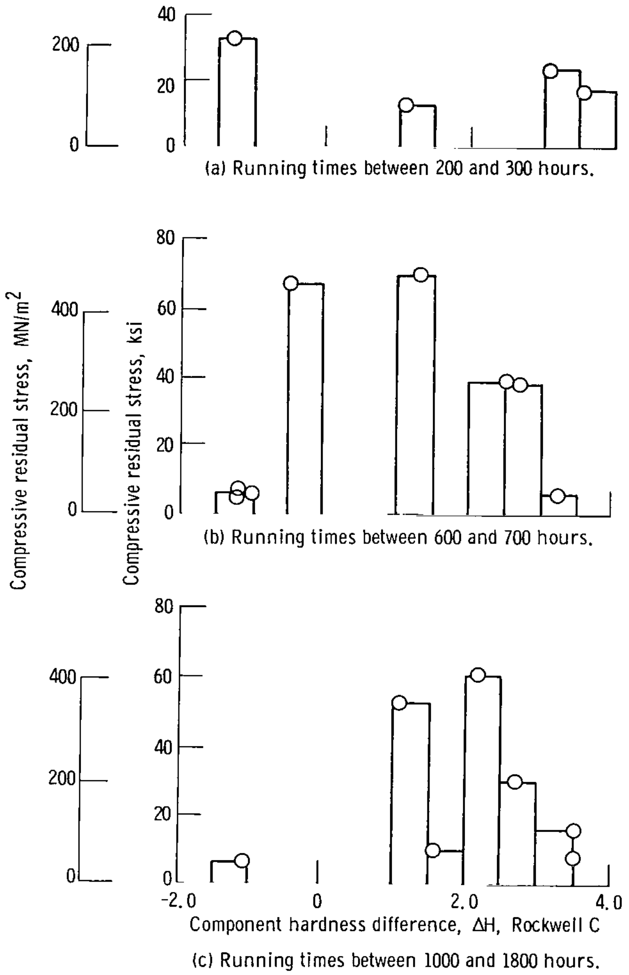


Figure 8. - Compressive residual stress as function of component hardness difference ΔH (ball hardness minus race hardness) for 207-size deep-groove bearing inner races. Depth below inner-race running track surface, 0.006 inch (0.015 cm); ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added.

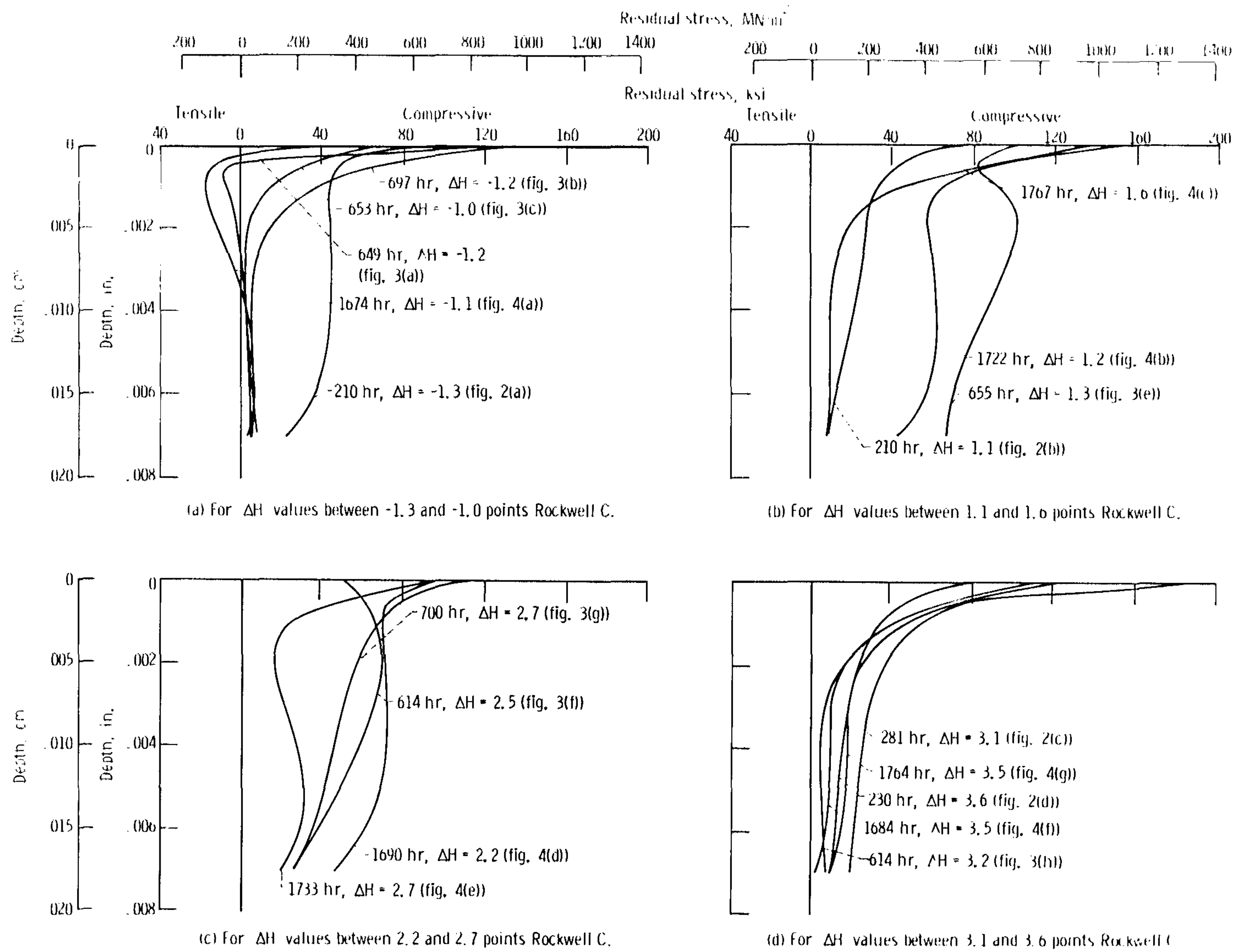


Figure 9. - Residual stress as function of depth with various running times for 207-size deep-groove bearing inner races.

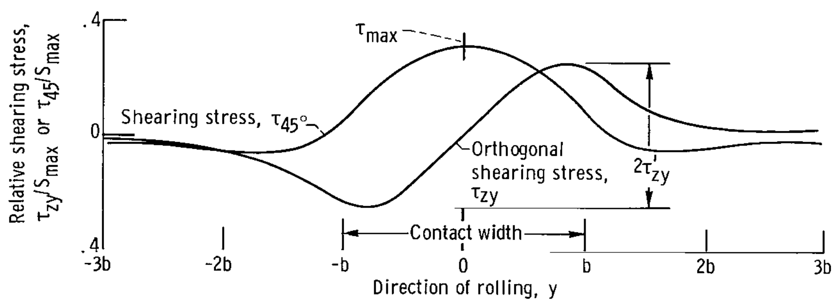
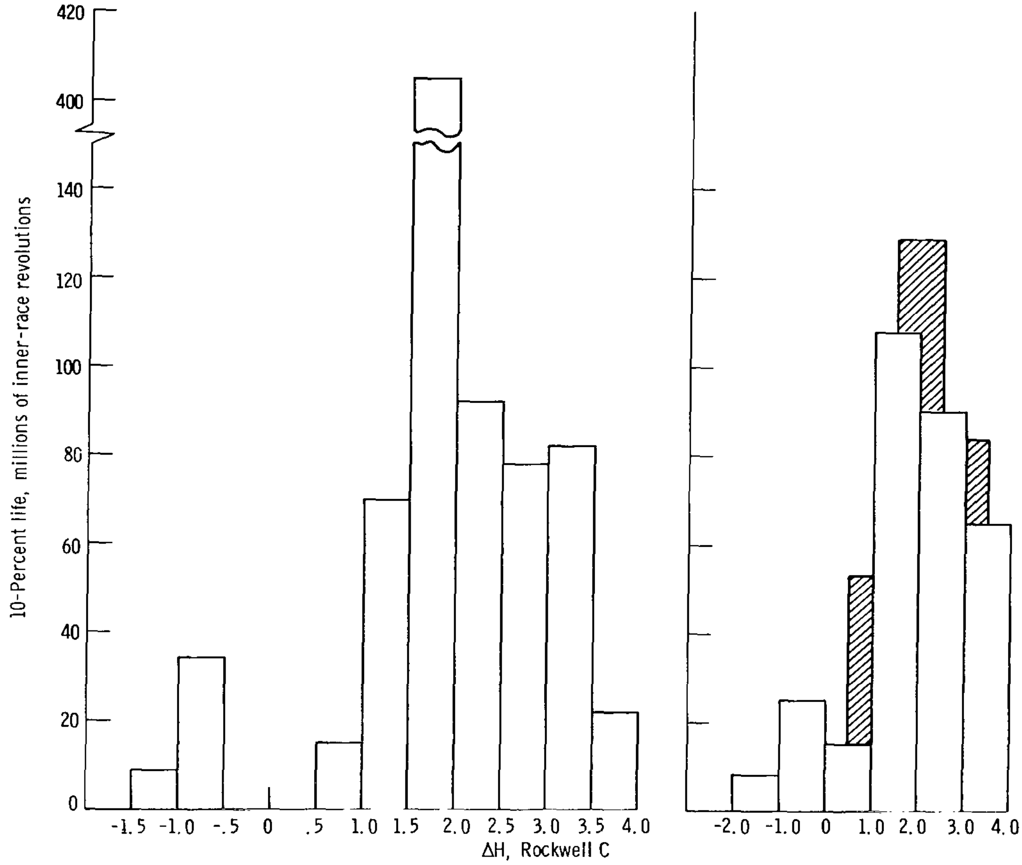


Figure 10. - Variation of shearing and orthogonal shearing stresses on plane at depth below rolling surface.



(a) Actual ΔH increment, 0.5. (b) Actual ΔH increment, 1.0.

Figure 11. - 10-Percent life as function of component hardness difference ΔH (ball hardness minus race hardness) for 207-size deep-groove ball bearings. Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added (refs. 7 and 8).

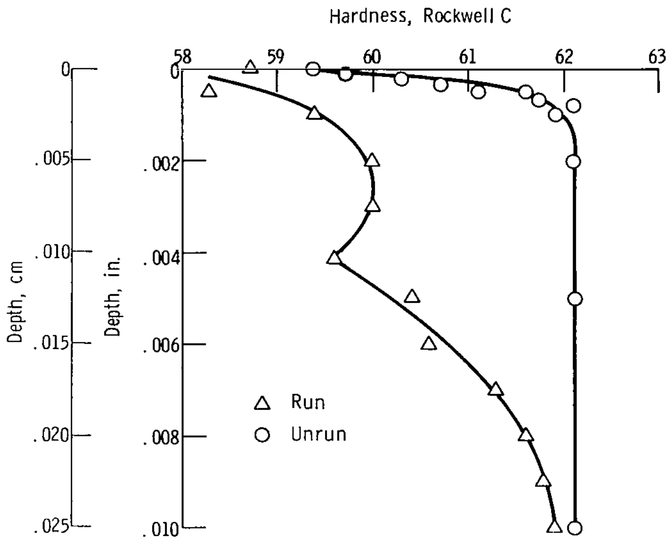
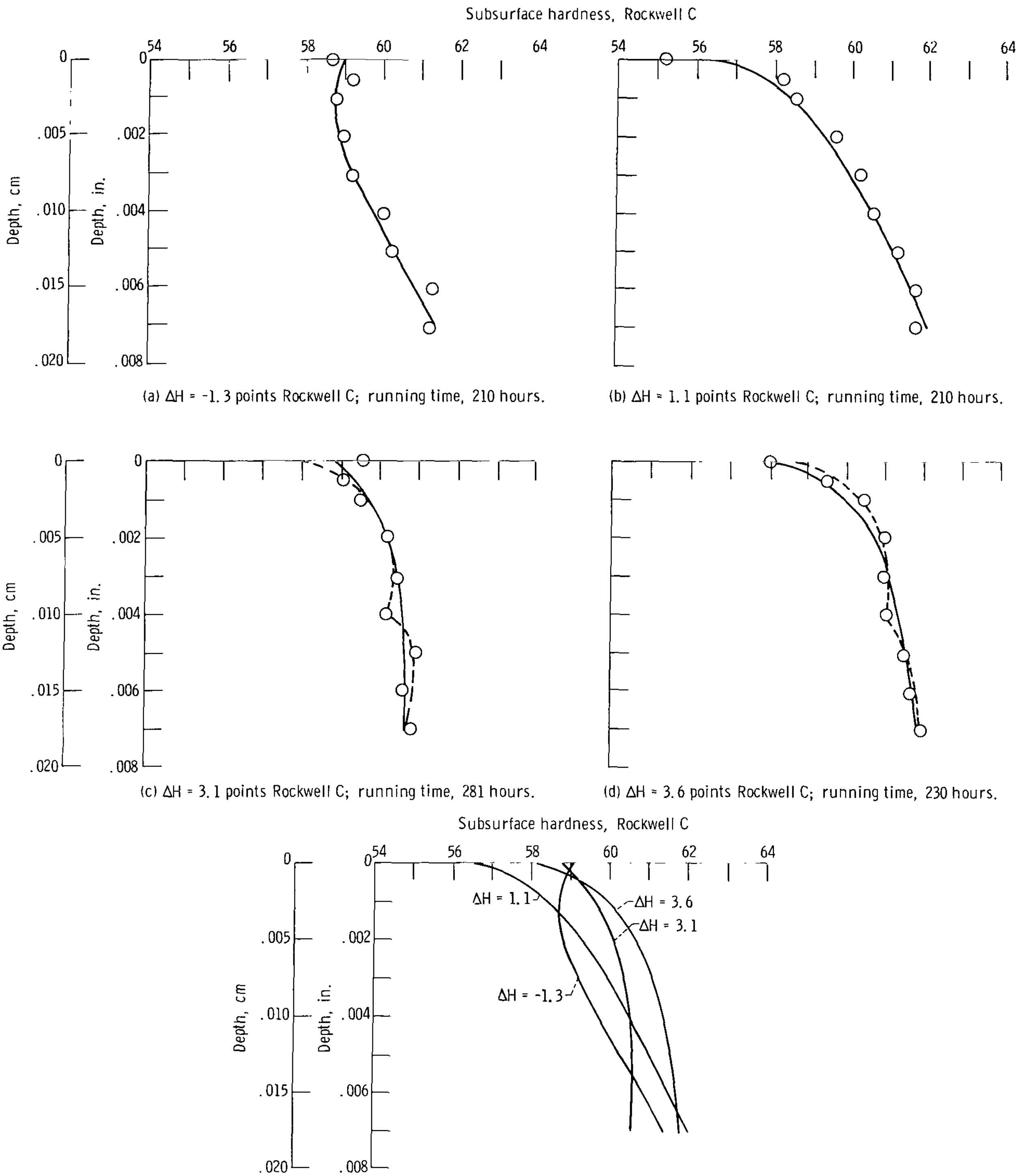


Figure 12. - Race hardness as function of depth below surface of 207-size deep-groove bearing inner races in both run (duration, 3480 hr) and unrun condition. Component hardness difference, ΔH = 2.0 (ref. 7).



(a) ΔH = -1.3 points Rockwell C; running time, 210 hours.

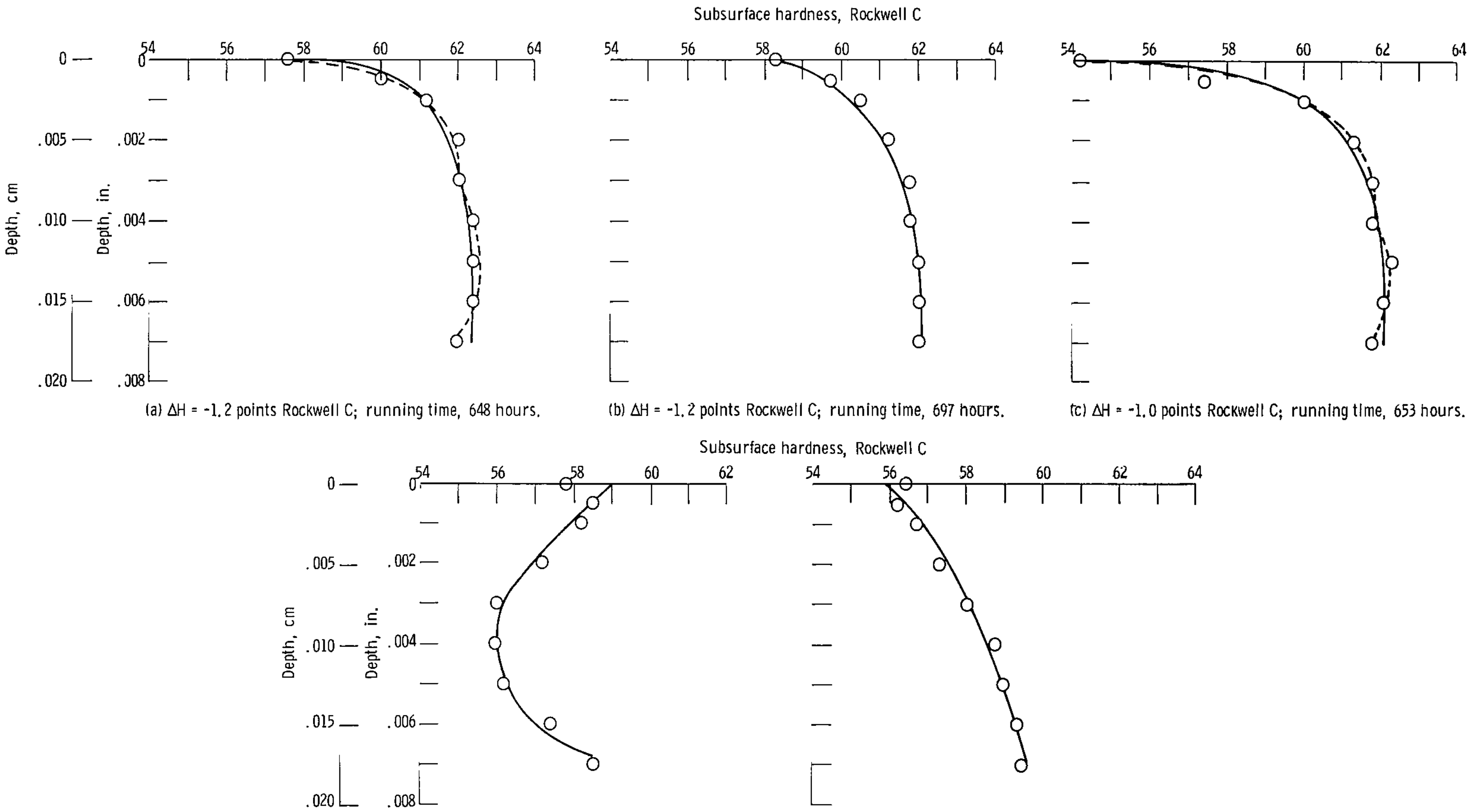
(b) ΔH = 1.1 points Rockwell C; running time, 210 hours.

(c) ΔH = 3.1 points Rockwell C; running time, 281 hours.

(d) ΔH = 3.6 points Rockwell C; running time, 230 hours.

(e) Summary of hardnesses.

Figure 13. - Subsurface Rockwell C hardness as function of depth for 207-size deep-groove bearing inner races with various values of component hardness difference ΔH (ball hardness minus race hardness). Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added; running times, between 200 and 300 hours.



(a) ΔH = -1.2 points Rockwell C; running time, 648 hours.

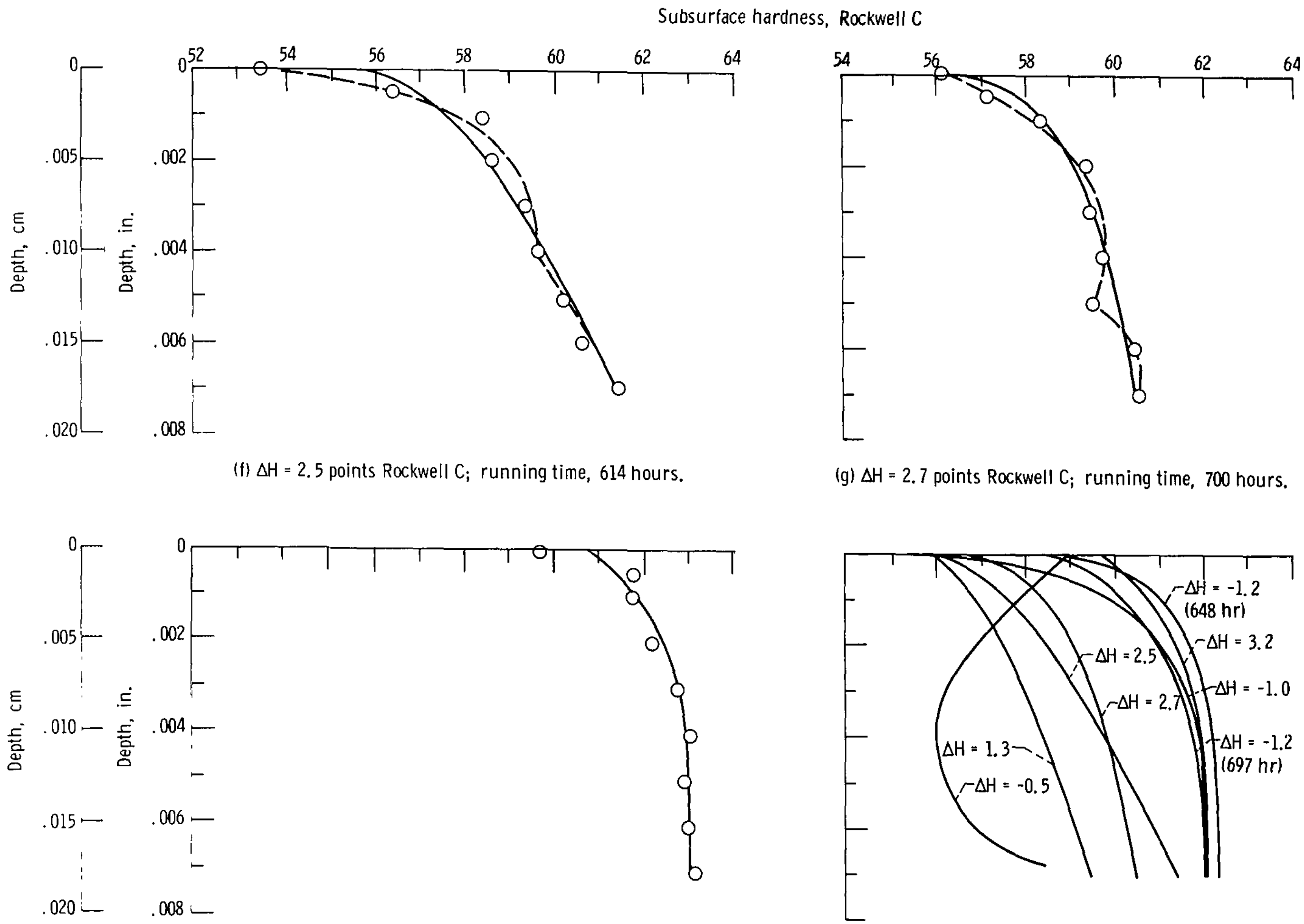
(b) ΔH = -1.2 points Rockwell C; running time, 697 hours.

(c) ΔH = -1.0 points Rockwell C; running time, 653 hours.

(d) ΔH = -0.5 points Rockwell C; running time, 691 hours.

(e) ΔH = 1.3 points Rockwell C; running time, 665 hours.

Figure 14. - Subsurface Rockwell C hardness as function of depth for 207-size deep-groove bearing inner races with various values of component hardness difference ΔH (ball hardness minus race hardness). Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added; running times, between 600 and 700 hours.



(f) ΔH = 2.5 points Rockwell C; running time, 614 hours.

(g) ΔH = 2.7 points Rockwell C; running time, 700 hours.

(h) ΔH = 3.2 points Rockwell C; running time, 614 hours.

(i) Summary of hardnesses.

Figure 14. - Concluded.

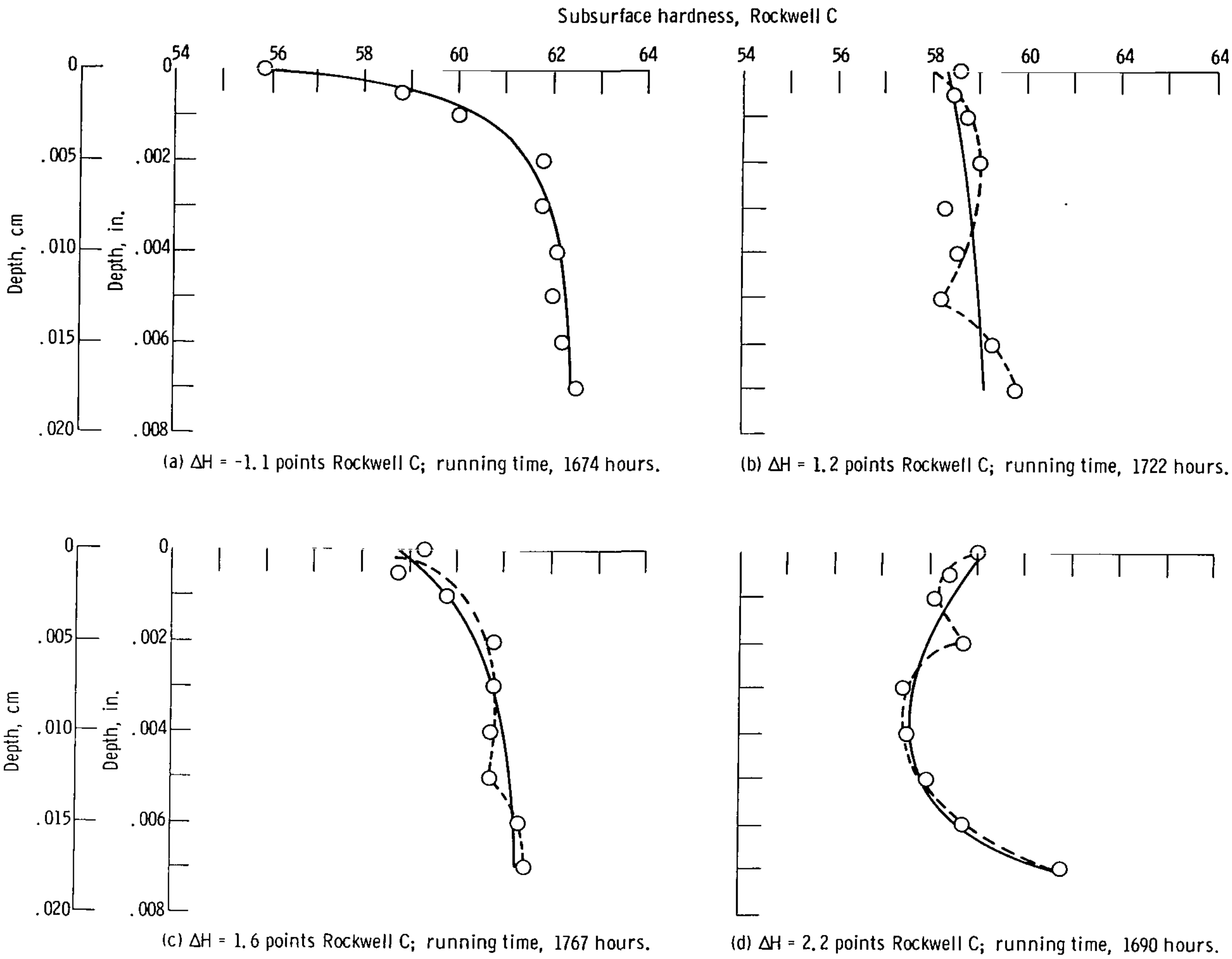
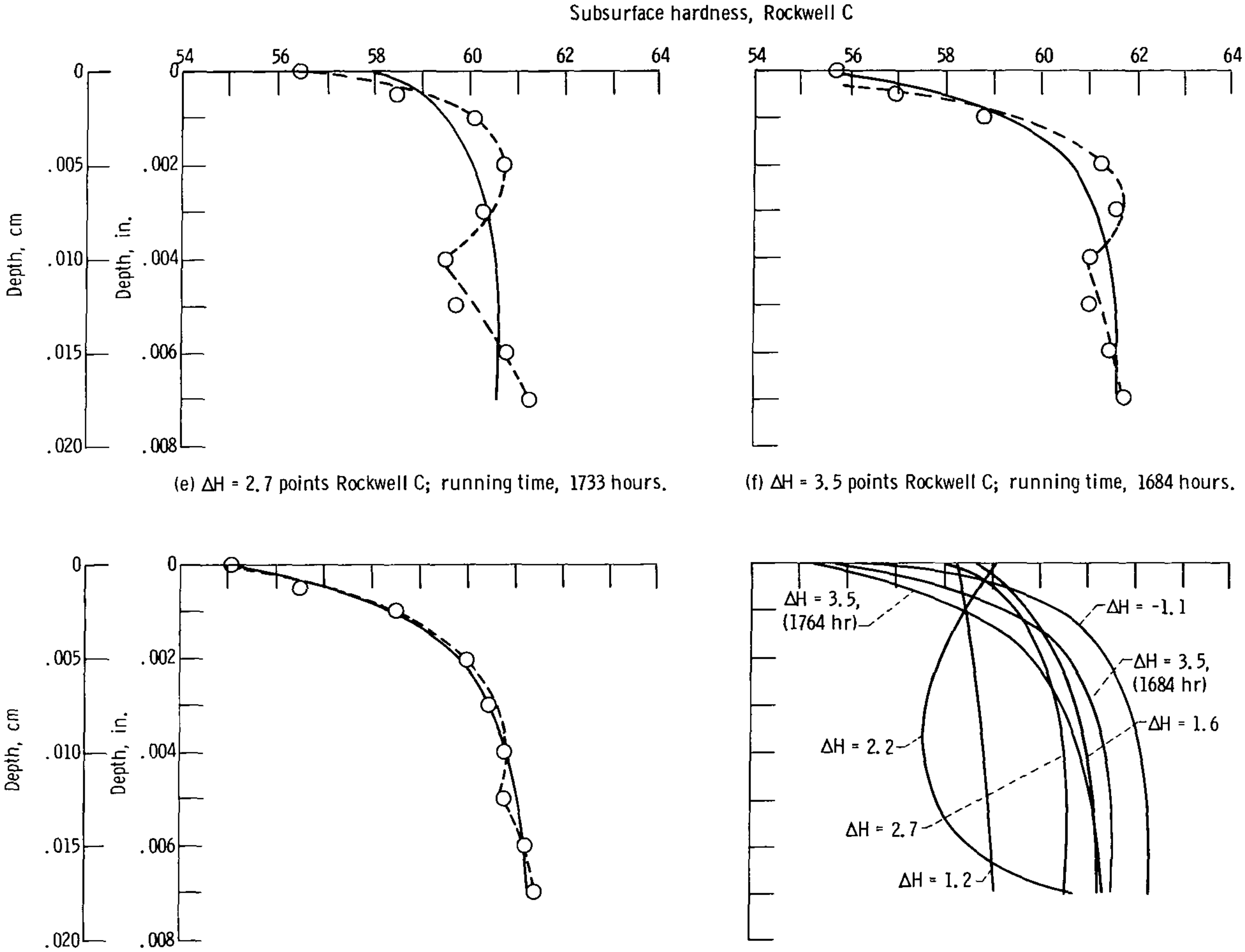


Figure 15. - Subsurface Rockwell C hardness as function of depth for 207-size deep-groove bearing inner races for values of component hardness difference ΔH (ball hardness minus race hardness). Ball and race material, SAE 52100 steel; radial load, 1320 pounds (5874 N); inner-race speed, 2750 rpm; no heat added; running times, between 1600 and 1800 hours.



(e) ΔH = 2.7 points Rockwell C; running time, 1733 hours.

(f) ΔH = 3.5 points Rockwell C; running time, 1684 hours.

(g) ΔH = 3.5 points Rockwell C; running time, 1764 hours.

(h) Summary of hardnesses.

Figure 15. - Concluded.

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